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Feasibility Study on the Utilization of Mixed Oxide Fuel in Korean 900MWe PWR Core Through Conceptual Core Nuclear Design and Analysis

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Abstract

The neutronic feasibility of typical Korean three-loop 900MWe class PWR core loaded with mixed oxide fuels for both annual and 18-month cycle strategies has been investigated as a means for spent fuel management. For this study, a method of determining equivalent plutonium content was developed under the equivalence concept which gives the same cycle length as uranium fuel. Optimal plutonium zoning within the MOX assembly was also designed with the aim of minimizing the peak rod power. Conceptual core designs have been developed for equilibrium cycle with the following variations: annual and 18-month cycle, 1/3 and full MOX loading schemes, and typical and high moderation lattice. The analysis of key core physics parameters shows that in all cases considered satisfactory core designs seem to be feasible, though addition of control rod system and change in Technical Specification for soluble boron concentration are required for full MOX loading in order to meet the current design requirements.

1. Introduction

Although the recycling of the plutonium from spent fuel has led to the political debate, many countries such as Germany[1-4], France[5-10], Belgium[7], and Japan[11-12] have continuously developed and matured the technologies to recycle the plutonium in thermal reactors. Since the introduction in 1960s, more than seven PWRs have been loaded with mixed-oxide fuel in Germany. As of 1986 in France, a generic safety analysis report was issued, and use of MOX up to 30 % in a reload of three batch loading strategy was demonstrated. At present, a total of sixteen reactors in France have been already licensed to use MOX fuel and twelve additional reactors are technically designed to receive MOX fuel. Belgium has utilized MOX fuel in BR3 reactor since 1963. MOX demonstration in Japan was started in 1986 at Tsuruga-1 for BWR and in 1988 at Mihama-1 for PWR. The Atomic Energy Commission of Japan decided that Japan would promote systematic utilization of MOX fuel in light water reactors. As seen in the above statements, MOX fuel has been irradiated in many LWRs in foreign countries and considered as a practical method for recycling of spent fuel.

Nuclear generated electricity plays vital role in Korea by accounting for nearly 40% of total electric power generation in recent years, and this trend is expected to continue in the years to come. The continuous expansion and development of nuclear power program increases the cumulative amount of spent fuels discharged from reactor cores. The quantities of heavy metal in spent fuels unloaded from a PWR (900MWe) and a PHWR(700MWe) are estimated to be about 20 and 90 tonnes annually, respectively. Following the nuclear power development plan, the operating nuclear units will result in an accumulation of approximately 8,000 tHM of spent nuclear fuels in Korea by the year 2006. This amount of spent nuclear fuel contains about 50 tonnes of plutonium which represent significant amount of semi-domestic energy resource, and thus cannot simply be ignored. Recycling of spent fuels can provide Korea with many attractive benefits; it will help to mitigate storage need of spent fuel, and contribute to the recycling of resources and the protection of natural environment through the reduction of radioactive wastes. Taking into account the very specific situation of Korea, two types of recycling could be considered in Korea: recycling of spent fuels into PWRs and PHWRs. The technology development of the Direct Use of spent PWR fuel In CANDU (DUPIC) has been under progress for some years.

Since the commercial use of MOX in LWRs is already taking place routinely in several European countries, it can be implemented without significant R&D effort on our part. Accordingly various PWR core designs loaded with MOX fuels have been evaluated in view of neutronic feasibility and recycled fuel consumption as a means of spent fuel management. For this study a 3-loop 900 MWe class PWR serves as the reference plant for developing equilibrium core designs. It was assumed that existing PWRs and fuel assemblies are used for the design of 1/3- and fully-loaded MOX cores, and system and design modifications are limited to within practical engineering constraints so that they can be readily implemented. Since recent operating strategy for Korean PWRs adopts 18-month cycle, both annual and 18-month cycle schemes are covered in conjunction with low-leakage fuel loadings. The increasing plutonium inventories including separated civil plutonium and weapon-originated plutonium call for effective means of plutonium management, and consequently the focus of recent studies on the plutonium recycling is shifted to the capability and special design features of fully-loaded MOX cores.[13,14] Thus fully-loaded MOX core capability has been also evaluated in terms of recycled fuel consumption and neutronic feasibility. Additionally investigated is the effect of high moderation fuel lattice[15] on the fully-loaded MOX core design.

2. MOX Fuel Assembly Design

The variation of cross-sections of plutonium isotopes with energy is more complex than those of uranium isotopes. The absorption cross sections of main fissile plutonium isotopes are about two times larger than those of ^{235}U in thermal neutron spectrum which result in smaller reactivity worths of control rod, soluble boron and xenon in MOX fuel. In the neutron energy range of 0.3eV to 1.5eV, the large resonance absorption cross-sections of plutonium isotopes characterize the nuclear behavior of MOX. The neutron-gamma reactions of plutonium isotopes by which higher plutonium isotopes are produced make much flatter variation of reactivity with burnup for MOX than for uranium fuel. Because of flatter variation of reactivity and larger absorption, a method has to be developed to determine the equivalent plutonium content and optimal zoning for MOX assembly design.

2.1. Determination of the Equivalent Plutonium Content

Due to slower decrease of reactivity with burnup for MOX fuel, it is necessary to determine the plutonium content of MOX fuel reactively equivalent to the UO_2 fuel. The concept of equivalence adopted in our study states that both fuels should provide the same cycle length for equilibrium cores.

According to the linear reactivity model, equilibrium cycle length of the core loaded with the constant enriched fuel is given by[16]

$$X = \frac{\rho^0}{A}\cdot\left(\frac{2}{n+1}\right) \qquad (1)$$

where

X = equilibrium cycle length,
ρ^0 = initial reactivity of feed fuel,
A = rate of reactivity change per unit of burnup,
n = number of regions in the core.

Under the condition of same number of regions for both the UO_2 and MOX fuels, we derive the following simple equivalence relation to give the same equilibrium cycle length for UO_2 and MOX cores ;

$$\frac{\rho^0_{UO_2}}{A_{UO_2}} = \frac{\rho^0_{MOX}}{A_{MOX}} \qquad (2)$$

where

$\rho^0_{UO_2}$ and ρ^0_{MOX} = initial reactivities of uranium and MOX fuel,
A_{UO_2} and A_{MOX} = rates of reactivity change per unit burnup of uranium and MOX fuel.

$\frac{\rho^0_{UO_2}}{A_{UO_2}}$ $\left(= \frac{\rho^0_{MOX}}{A_{MOX}}\right)$ in Eq.(2) means the fuel burnup at zero reactivity. Therefore the MOX fuel equivalent to UO_2 fuel is simply the one that shows the reactivity curve crossing the point $\left(0, \frac{\rho^0_{UO_2}}{A_{UO_2}}\right)$ in the reactivity-burnup coordinates. The equivalent plutonium content of MOX fuel was estimated by this graphic method and corrected by multi-cycle scoping results with FLOSA code[17]. The equivalent plutonium contents of MOX fuels to uranium oxide fuels are listed in Table 1. It was estimated that 3.1 w/o of plutonium fissile contents with natural uranium as carrier and 4.0 w/o of plutonium fissile with depleted uranium as carrier are equivalent to 3.5 w/o and 4.0 w/o uranium fuel, respectively. The usefulness of graphic method and multi-cycle scoping analysis is shown in Table 2 which compares to SIEMENS' equivalent plutonium content of MOX with the same plutonium composition and carrier as those in this paper.

The equivalent plutonium contents listed in Table

Table 2. Comparison of the Equivalent Plutonium Contents

^{235}U Enrichment of Uranium Fuel	Equivalent Plutonium Contents (Pu-fissile w/o)	
	KAERI Predicted	SIEMENS
3.2	2.86	2.83
3.4	3.02	3.07[a]
3.5	3.10	3.07[a]
4.0	3.50	3.70

a) SIEMENS uses same plutonium content for both MOX fuels equivalent to 3.4 and 3.5 w/o of ^{235}U enriched UO_2 fuel.

Table 1. Estimation of Equivalent Plutonium Contents

^{235}U w/o	Equivalent Plutonium Contents(Pu-fissile w/o)				
		Graphic Method		Estimated	
	FLOSA (with Nat. Uranium)	with Nat. Uranium (0.711w/o of ^{235}U)	with Depl. Uranium (0.225w/o of ^{235}U)	with Nat. Uranium (0.711w/o of ^{235}U)	with Depl. Uranium (0.225w/o of ^{235}U)
3.3	2.933				
3.4	3.032				
3.5	3.130(4.4total)	2.99(4.2 total)	3.39(4.76 total)	3.1	3.5
3.6	3.225				
3.7	3.317				
3.9	3.493				
4.0	3.576(5.022total)	3.42(4.8 total)	3.90(5.48 total)	3.5	4.0
4.1	3.658				
4.3	3.815				
4.5	3.965(5.57total)	3.92(5.5 total)	4.41(6.2 total)	4.0	4.5

Table 3. Equivalent Reactivity Factor of Each Plutonium Isotope

Plutonium Isotope	Equivalent Reactivity Factor
^{239}Pu	100%
^{240}Pu	−7%
^{241}Pu	115%
^{242}Pu	105%

1 were determined for the composition of plutonium isotopes : ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{242}Pu are 1.8, 59.0, 23.0, 12.2 and 4.0 w/o, respectively. Since the real plutonium composition used in MOX fabrication stage can be different from the assumed value, the final plutonium content will have to be adjusted according to the following formula;

$$T' = \frac{\sum_i \alpha_i \cdot Pu_i}{\sum_i \alpha_i \cdot Pu_i'} \cdot T \qquad (3)$$

where T and T' are the reference and the adjusted contents of plutonium in MOX fuel, α_i is the equivalent reactivity factor of each plutonium isotope which are listed in Table 3, and Pu_i and Pu_i' are the plutonium isotope vectors of reference MOX and to be designed.

2.2. Optimal Zoning in MOX Fuel Assembly

When MOX fuel assemblies are intermixed with uranium fuels in the core, the peripheral rods in MOX fuel assembly experience steep gradient of thermal neutron flux leading to higher production of power than the interior rods because they are strongly affected by the incoming thermal neutron stream from the adjacent UO_2 fuel assembly. Therefore MOX fuel assembly design requires enrichment zoning over the fuel assembly in order to minimize the peak rod power in the outer region. Fig.1 and Fig.2 show the optimal zoning in the MOX fuel assemblies with three different plutonium concentrations.

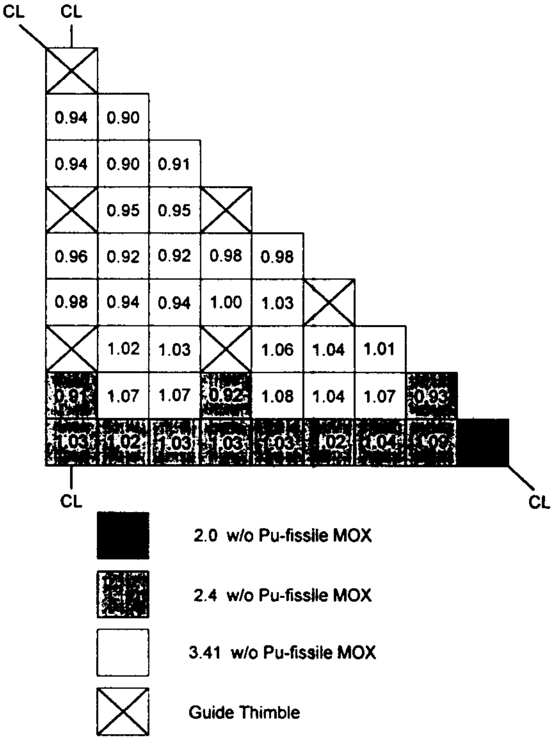


Fig. 1. Zoning and Power Distribution of MOX Assembly Equivalent to 3.5 w/o UO_2

In the case of fully-loaded MOX core, however, enrichment zoning is not needed any more, thereby eliminating manufacturing complexity. The rodwise power distribution within the assembly in a fully-loaded MOX core is rather flat as shown in Fig.3. But the powers of neighboring rods to guide thimbles tend to be high, which still suggests the benefit of zoning around guide thimbles in certain core configurations to control peak rod power.

Low-leakage loading requires to employ burnable poisons in some fresh MOX fuels so that excess core reactivity and peak pin power can be controlled. Gadolinia rod with 9 w/o Gd content was used as burnable poison in this study. As shown in Fig.4, it was found that the reactivity holddown was reduced by half, but burnout time is extended twofold, compared to uranium fuel assembly containing the same gadolinia rods, due to hardened spectrum. Lower reactivity worth together with extended burnout time of gadolinia rod in MOX fuel suggests more investi-

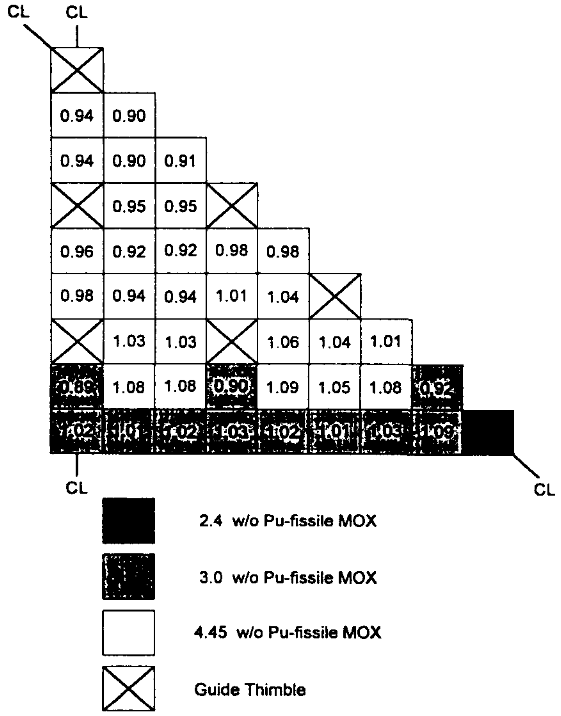


Fig. 2. Zoning and Power Distribution of MOX Assembly Equivalent to 4.0 w/o UO_2

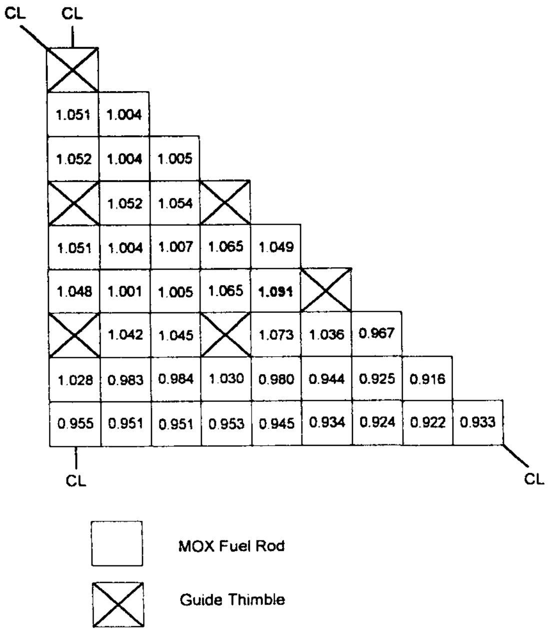


Fig. 3. Rodwise Power Distribution in a MOX Fuel Assembly for Full MOX Core

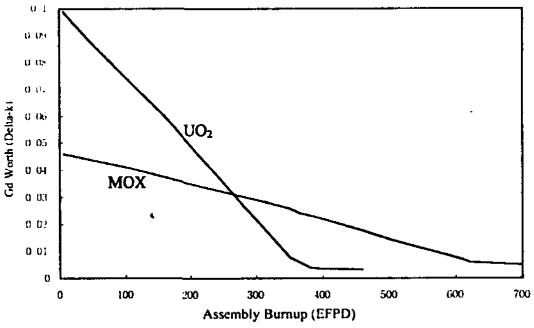


Fig. 4. Gadolinia Worth in MOX and UO_2 Fuel

gation to optimize burnable poison design.

3. Nuclear Analysis of MOX Cores

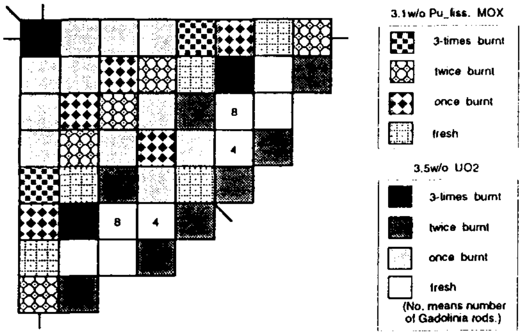
3.1. Fuel Management

Three types of conceptual core designs have been developed from transition to equilibrium cycles for a 3-loop PWR with 900 MWe capacity:

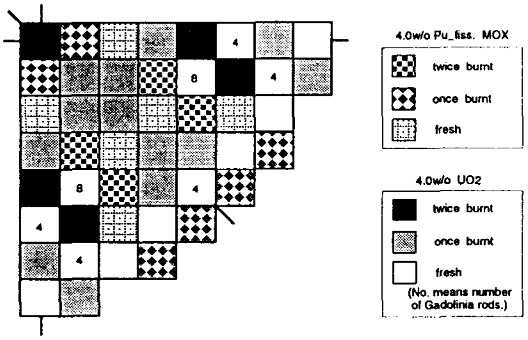
1) 1/3-loaded MOX cores for annual and 18-month cycles
2) fully-loaded MOX cores for annual and 18-month cycles
3) fully-loaded MOX core with high moderation lattice for 18-month cycle.

The fuel cycle characteristics for MOX and UO_2 cores are summarized in Table 4. The fuel loading strategy for annual fuel cycle assumed that each 48-fuel assembly feed batch consists of 16 MOX assemblies with 3.1w/o fissile plutonium content and 32 UO_2 fuel assemblies with 3.5w/o enriched ^{235}U. For 18-month fuel cycle it was assumed that each 64-fuel assembly feed batch consists of 20 MOX assemblies with 4.0w/o fissile plutonium content and 44 UO_2 fuel assemblies with 4.0w/o enriched ^{235}U.

Loading patterns of equilibrium 1/3-loaded MOX cores for annual and 18-month cycles are shown in Fig.5. Low-leakage loading scheme made some fresh MOX and UO_2 fuel assemblies take inboard locations. The cycle lengths of annual and 18-month

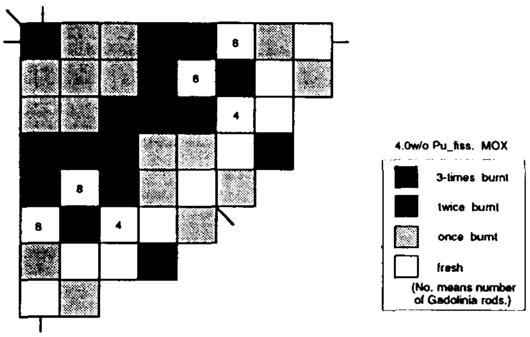


a) Annual Cycle

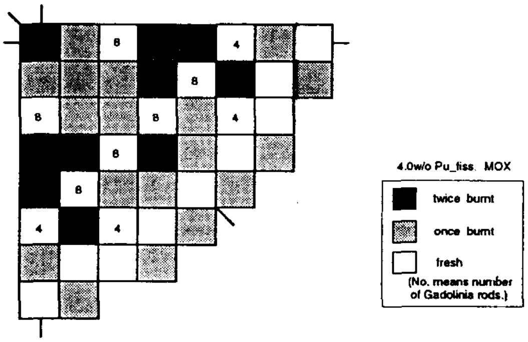


b) 18-Month Cycle

Fig. 5. Loading Patterns for 1/3-Loaded MOX Equilibrium Cores



a) Annual Cycle



b) 18-Month Cycle

Fig. 6. Loading Patterns for Fully-Loaded MOX Equilibrium Cores

1/3-loaded MOX cores are 12.0 and 16.53 MWD/MtM which are very close to those of UO_2 cores, 12.22 and 16.60 MWD/MtM. This demonstrates our method to determine the equivalent plutonium content of MOX fuel.

Three batches of MOX fuels with 1.6, 2.4 and 4.0 w/o fissile plutonium with depleted uranium as matrix material were assumed to be loaded in the initial fully-loaded MOX core. For subsequent reload cycles low-leakage fuel management scheme was applied with the feed of 4.0 w/o fissile plutonium fuel. Fifty two and sixty four MOX fuel assemblies were reloaded for annual cycle and 18-month cycle respectively. Loading patterns of equilibrium cores are shown in Fig.6. The low-leakage loading strategy made most of fresh fuel assemblies occupy inboard locations in which some fresh MOX assemblies bear four or eight gadolinia rods mainly to control excess core reactivity. High moderation lattice case is intended to see the effect of lattice change on fully-loaded MOX core. The high moderation fuel lattice was constructed in such a way to increase the moderation ratio from 1.7 of reference MOX fuel assembly to 1.9 by reducing rod diameter to the extent that it does not bring about any engineering impact practically.

The fuel cycle characteristics for fully-loaded MOX cores are also summarized in Table 4. The cycle lengths of annual and 18-month standard MOX cores are 12.64 and 15.10 GWD/MtM, while high moderation case shows better performance with the longer cycle length of 17.0 GWD/MtM. In all cases the maximum assembly discharge burnup exceeds the cur-

Table 4. MOX and UO_2 Core Characteristics

Fuel Cycle Type	UO_2 Core		1/3-Loaded MOX Core		Fully-Loaded MOX Core		High Moderated Full MOX Core
Core Characteristics	Annual	18 Month	Annual	18 Month	Annual	18 Month	18 Month
Number of Fuel Assemblies in a Core							
MOX Fuel Assembly	-	-	52	56	157	157	157
UO_2 Fuel Assembly	157	157	105	101	-	-	-
Number of Fresh Fuel Assemblies							
MOX Fuel without gadolinia	-	-	16	20	32	32	32
MOX Fuel with 4 gadolinia	-	-	-	-	8	12	12
MOX Fuel with 8 gadolinia	-	-	-	-	12	20	20
UO_2 Fuel	48	64	32	44	52	64	64
Fuel Assembly Specification							
Fissile Plutonium Content in MOX (w/o)	-	-	3.1	4.0	4.0	4.0	4.0
U^{235} Enrichment in MOX (w/o)	-	-	0.71	0.225	0.225	0.225	0.225
U^{235} Enrichment in UO_2 (w/o)	3.5	4.0	3.5	4.0	-	-	-
Cycle Length (MWD/MtM)	12.22	16.60	12.00	16.53	12.64	15.10	17.00
Fuel Burnup (MWD/MtM)							
MOX Fuel Batch Burnup	-	-	39.74	45.53	38.24	36.97	41.60
MOX Fuel Assembly Maximum Burnup	-	-	41.65	47.23	46.65	46.42	51.00
UO_2 Fuel Batch Burnup	37.59	40.79	35.45	38.35	-	-	-
UO_2 Fuel Assembly Maximum Burnup	43.65	50.03	41.25	47.55	-	-	-

rent practice of MOX utilization. However, we expect that further development of high burnup MOX fuel will extend the allowable burnup limit well beyond the present one in the next ten years.

3.2 Nuclear Characteristics of MOX Cores

Some key core physics parameters of designed cores are compared each other in Table 5. A major difference of MOX loaded core is the hardening of thermal neutron spectrum in the core which alters various core physics parameters, mainly reactivity-related ones. Because of hardened spectrum the neutron absorption capability of soluble boron, control rod and xenon which are thermal neutron absorbers becomes lower proportionally to the fraction of MOX fuel. Thus the reactivity worths of soluble boron, control rod and xenon are accordingly reduced in MOX loaded core. The consequence of smaller soluble boron worth in MOX cores is reflected in the high critical boron concentrations, which require modifications in the boron handling systems for some MOX cores. Moderator and isothermal temperature coefficients are highly more negative in MOX cores than UO_2 core due to hardened spectrum with MOX fuel which increases the neutron leakage. Since the content of ^{240}Pu isotope having large resonance absorption cross section at around 1 eV is higher in MOX core than in UO_2 core, MOX cores have more negative Doppler coefficients.

Because of smaller control rod worths, the shutdown margins of MOX cores at BOC and EOC for

Table 5. Core Nuclear Characteristics of MOX and UO$_2$ Cores

Fuel Cycle	UO$_2$ Core	1/3-Loaded MOX Core		Fully-Loaded MOX Core			
Nuclear Parameter		Annual Cycle	18 Month Cycle	Annual Cycle	18 Month Cycle	RCCA Addition	High Moderated Lattice
Boron Concentration							
Refueling CB, ARI(k<0.95)	>2066	>2187	>2674	>3969	>4144	>3712	>3762
Shutdown(k=0.98) with ARI,HZP	1313	971	1372	1506	1843	999	1808
Shutdown(k=0.98) with ARO,HZP	2374	2131	2564	3079	3392	-	3221
To control at HZP, ARO, (k=1.0)	2100	1819	2213	2531	2830	-	2720
To control at HZP, ARI, (k=1.0)	1056	680	1010	992	1313	-	1336
To control at HFP, ARO, (k=1.0)							
0 GWD/MtM, No Xenon	1907	1519	1908	1920	2234	-	2241
240 GWD/MtM, Equilibrium Xenon	1541	1155	1520	1453	1754	-	1788
Moderator Temperature Coefficient at HFP (pcm/℃)							
BOC/EOC	−10/−56	−28/−58	−23/−60	−43/−67	−37/−67	-	−32/−64
Isothermal Temperature Coefficient at HZP at BOC (pcm/℃)	1.54	−15.65	−11.45	−29.46	−24.44	-	−20.36
Doppler Temperature Coefficient at near EOC (pcm/℃)	−3.96	−4.04	−4.06	−4.14	−4.17	-	−4.11
Boron Worth at HFP (pcm/ppm)							
BOC/EOC	−7.2/−8.8	−6.5/−7.8	−5.7/−7.1	−3.6/−4.5	−3.5/−4.5	-	−3.9/−5.3
Xenon Worth (pcm)							
BOC/EOC	2721/2848	2519/2674	2338/2545	1816/2133	1813/2196	-	1879/2309
Total Control Rod Worth (pcm)							
BOC/EOC	8004/8350	7240/8170	7260/7690	5840/6250	5560/6100	8671/9783	5726/6374
Shutdown Margin (%$\Delta\rho$)							
BOC/EOC	4.26/2.85	3.44/2.65	3.47/2.63	1.81/1.31	1.77/1.14	4.02/3.42	2.09/1.53

annual and 18 months cycles are generally decreased. The required minimum shutdown margin is 1.77% $\Delta\rho$ for UO$_2$ core. This limit is still maintained for 1/3-loaded MOX cases. However, the standard fully-loaded MOX cores do not maintain the minimum shutdown margin at EOC. The shutdown margins of high moderation lattice core are larger but still do not meet the minimum shutdown margin of 1.77 %$\Delta\rho$. The minimum shutdown margin requirement can be satisfied for standard fully-loaded MOX cores by increasing the number of control rod clusters from 48 to 68. This modification can be accommodated without any difficulty for present 900 MWe PWRs in Korea.

The power distributions of MOX cores were not significantly different from those of uranium cores. The axial power distributions of MOX cores at HFP at several burnup stages, however, are bottom skew-

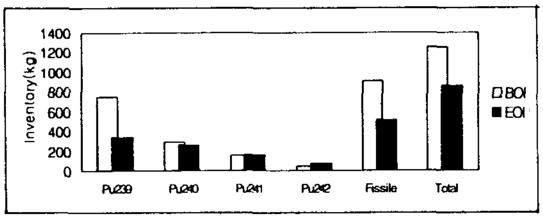
Table 6. Variation of Plutonium Inventory for Equilibrium Cycle (Kg)

Pu Isotope	1/3 MOX Core		Full MOX Core for Annual Cycle		Full MOX Core for 18 Month Cycle		Full MOX Core with High Moderation Lattice	
	BOC	EOC	BOC	EOC	BOC	EOC	BOC	EOC
^{239}Pu	588.6	560.6	1771.2	1362.4	1858.6	1387.2	1696.6	1174.9
^{240}Pu	276.5	302.9	888.0	861.6	890.7	864.6	850.9	814.2
^{241}Pu	160.1	183.1	513.2	530.0	505.4	525.5	478.9	484.9
^{242}Pu	60.0	81.1	187.2	225.2	180.8	224.1	179.9	232.2
Fissile Pu	748.7	743.7	2284.4	1892.4	2364.0	1912.7	2175.5	1659.8
Total Pu	1085.2	1127.7	3359.6	2979.2	3435.5	3001.4	3206.3	2706.2

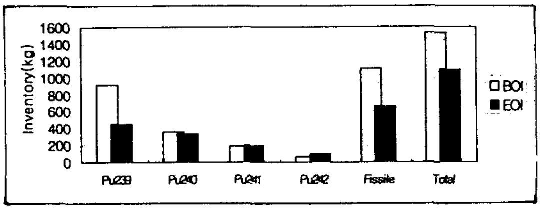
ed which resulted from more negative moderator temperature coefficient.

3.3. Evolution of Plutonium Inventory

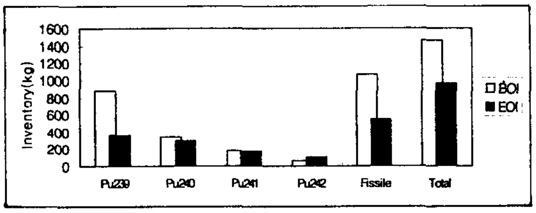
Table 6 compares the change of plutonium inventory at equilibrium cycle in 1/3- and fully-loaded MOX cores. The plutonium inventory of 1/3-loaded MOX core increased slightly from 1085kg to 1128kg because plutonium production in uranium fuel offset in-situ burning, but those of fully-loaded MOX cores decreased significantly. The fact implies that the current strategy of plutonium recycling (1/3 MOX loading) in PWRs has less merit in view of plutonium consumption. As shown in Table 6, the fully-loaded MOX core with high moderation lattice can be considered as the best plutonium consumer.



a) Annual Cycle, Batch Size=52



b) 18-Month Cycle, Batch Size=64



c) High Moderation Lattice, Batch Size=64

Fig. 7. Plutonium Inventory Before and After Irradiation

Fig.7 shows plutonium inventory of reload batch before and after irradiation. Fissile and total plutonium quantities at discharge are significantly reduced to 60 % and 70 % respectively of initial value for standard fully-loaded MOX cores. The reductions are more pronounced to 52 % and 66 % in the fully-loaded MOX core of high moderation lattice. The plutonium quality was degraded to some extent and remained nearly the same to about 60 % of fissile for all cases. High moderation lattice case indicates better performance, if not distinctive, in terms of plutonium consumption. It is estimated that one fully-loaded MOX core with 900 MWe capacity demands about 1 tonne of plutonium per year to be reloaded. This amount of plutonium requests reprocessing of spent nuclear fuels discharged from five 900 MWe nuclear power plants operating with uranium fuels.

4. Safety Analysis for 1/3-Loaded MOX Core

Effective delayed neutron fraction and prompt neutron life time for MOX core are generally shorter than those of UO_2 core. These parameters strongly affect core power transients occurred during very short period like prompt critical. Safety analysis has been performed for 1/3-loaded MOX core by using TASS code[18] on the most serious reactivity induced transients such as control rod ejection, steamline break accident and control rod withdrawal accident.

Control rod ejection analysis at zero power initial conditions has shown acceptable consequences. The lowered reactivity of ejected rod compensated the adverse effect of the effective delayed neutron fraction and prompt neutron lifetime. Fig.8 shows the average heat flux variation after steamline break accident. The reactivity insertion resulted from cool-down in primary loop becomes greater in MOX core due to more negative moderator temperature coefficient, leading to the larger peak heat flux by 4% than UO_2 core. However, the power peaking factor of MOX core at stuck rod configuration is reduced to 7.00 from 8.66 of UO_2 core due to the decreased control rod worth. As a result, steamline break accident for MOX core results in acceptable consequences. RCCA withdrawal accident analysis has also demonstrated no adverse consequences due to the reduced reactivity insertion by control rod withdrawal.

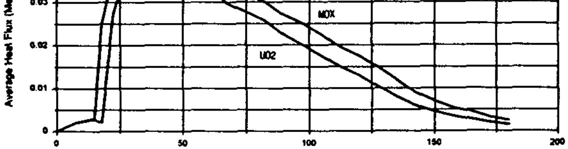


Fig.8. Average Heat Flux Variation during Steamline Break Accident

5. Conclusions

The neutronic feasibility of typical Korean three-loop 900MWe class PWR core loaded with mixed oxide fuels for both annual and 18-month cycle strategies has been investigated as a means for spent fuel management. For this study, a method of determining equivalent plutonium content was developed under the equivalence concept which gives the same cycle length as uranium fuel. Optimal plutonium zoning within the MOX assembly was also designed with the aim of minimizing the peak rod power.

Conceptual core designs have been developed for equilibrium cycle with the following variations: annual and 18-month cycle, 1/3 and full MOX loading schemes, and typical and high moderation lattice. The analysis of key core physics parameters shows that in all cases considered satisfactory core designs seem to be feasible, though addition of control rod system and change in Technical Specification for soluble boron concentration are required for full MOX loading in order to meet the current design requirements. Safety analysis on the most serious reactivity induced transients such as control rod ejection, steamline break accident and control rod withdrawal accident demonstrated acceptable consequences for 1/3-loaded MOX core. Therefore the 1/3 loading of MOX scheme in comparison to full loading of MOX is the most feasible and practical means in the near future to reuse the spent fuel from PWR in Korea.

With full MOX loading strategy, fissile and total plutonium quantities at discharge are significantly reduced to 60 % and 70 % respectively of initial value. It is estimated that one fully-loaded MOX core demands about 1 tonne of plutonium per year to be reloaded, equivalent to reprocessing of spent nuclear fuels discharged from five nuclear reactors operating with uranium fuels. Overall high moderation lattice core shows advantage in plutonium consumption and core nuclear characteristics, but further study on optimizing lattice design shall be required in order to take full benefit of over-moderation.

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